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(54) **Scene based nonuniformity correction for scanning infrared sensors**

Szenenabhängige Korrektur der Ungleichmässigkeit von abtastenden Infrarotsensoren

Correction de non-uniformité basée sur une scène pour détecteurs de balayage infra-rouge

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WO-A-90/09076 **DE-C- 4 300 781**
US-A- 5 065 444

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Description

BACKGROUND

- 5 [0001] The present invention relates generally to imaging sensors, and more particularly, to a scene based nonuniformity correction method for use with such imaging sensors.
- [0002] Nonuniformities appear at an output display of an imaging sensor as fixed pattern noise. The nonuniformities are described as noise because they result in undesirable information. The nonuniformities are described as a fixed pattern because their characteristics do not change (or change relatively slowly) with time. These nonuniformities may also
- 10 be thought of as detector gain and offset errors. In the method of the present invention, all errors are treated as offset errors. Thus, the present invention accurately measures the detector offsets using actual scene information.
- [0003] Once the offset errors have been measured, there are several ways in which the corrections may be applied. They may be used as the only source of error correction. They may also be used as fine offset correction terms in conjunction with coarse offset terms and gain correction terms. These other terms may be calculated using a number of
- 15 different methods. These methods include coarse offset terms calculated using a thermal reference source; coarse offset and gain terms calculated as part of system initialization; and fine gain terms calculated using thermal reference sources or scene-based methods.
- [0004] EP-A-0439912 discloses such a dynamic detector processing circuit for processing detector output data using detector-error-correcting offset coefficients.
- 20 [0005] In one current method employed by the assignee of the present invention, one or more thermal reference sources are used to measure nonuniformities for a scanning infrared sensor and provide data for the calculation of correction coefficients that are employed to correct for the nonuniformities. There are several disadvantages related to the use of a thermal reference source-based correction system. First, there is added mechanical complexity which leads to increased system cost. Secondly, system performance may suffer.
- 25 [0006] System performance suffers for two reasons. In many cases, a separate optical path is utilized for each thermal reference source. Thus, the correction coefficients calculated using the thermal reference source optical path may not be the proper ones for the optical path of the scanning infrared sensor. This leads to imperfect correction. In less sophisticated systems, the temperature of the thermal reference source cannot be controlled. In this case, the thermal reference source may not be at the same temperature as the scene that is viewed. The correction coefficients thus
- 30 correspond to the wrong part of the detector response curve. This also leads to imperfect correction. The present method avoids these problems by using scene temperature information. Furthermore, the present invention does not degrade the scene in any manner.
- [0007] WO-A-90/09076 discloses an apparatus and a method for providing scene-based nonuniformity compensation of an imaging system comprising an array of detectors and a processor which implements nonuniformity compensation
- 35 of the detectors using a feedback loop. The processor generates compensation terms which are subsequently combined in a summer with the output signals from the detector array. The method comprises median, antimedian and average filters. The system makes use of high-pass filtered regions of a fixed shape not associated with the image content.

SUMMARY OF THE INVENTION

- 40 [0008] As defined in claim 1, the present scene-based nonuniformity correction method is used to eliminate image defects in an imaging sensor or video system, such as a scanning infrared sensor or pushbroom sensor, for example, resulting from nonuniformities caused by an detector (focal plane array) and detector readout, for example. The present invention detects, measures, and corrects for nonuniformities in the video output of a imaging sensor without degrading
- 45 the image. A set of correction terms is calculated and applied to a video signal produced by the sensor using either a feedback or feedforward configuration. After the correction terms are applied, the resultant video signal is suitable for display or further processing.
- [0009] The video image generated by the imaging sensor is processed such that a vector representing an offset correction term is formed, and this vector is initially set to zero. Each element in this vector represents a correction term for a particular detector of the imaging sensor. The vector is applied to each pixel of the image by a processor as the pixels
- 50 are read from the focal plane array of the sensor.
- [0010] To measure the offset error, the image is separated into vertically oriented regions, each comprising a plurality of channels. The average of each channel within a region is computed and a set of region vectors is formed, such that there is one region vector for each region. Each region vector is then processed and regions whose edges are larger
- 55 than a predefined threshold are detected and marked. Then, each region vector is further separated into sub-regions. The isolated sub-regions are high-pass filtered without regard to adjacent sub-regions. The high-pass filter may be in the form of a finite impulse response (FIR) filter or an anti-median filter, for example. The anti-median filter is a nonlinear high-pass filter that converges very rapidly. Finally, the correction terms for each vertical region vector are averaged

together, resulting in a single correction vector that is applied to the video signal to reduce the effect of the nonuniformities.

[0011] The correction terms calculated for each vertical region may also be applied individually to each the detectors. In this case, the correction terms corresponding to a region are applied as the detector scans the scene and views a portion corresponding to that particular region. The correction terms are smoothed at region boundaries to eliminate noise due to boundary transitions. This second method is less sensitive to gain errors in the detector.

[0012] There are several advantages in using the present method. First the mechanical complexity of the imaging system is reduced, which leads to lower costs because fewer components are required and there is reduced labor required for manufacturing and testing. Secondly an imaging system incorporating the present invention provides better performance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

Fig. 1 shows a block diagram of a generic imaging sensor-system incorporating a scene based nonuniformity correction method in accordance with the principles of the present invention;

Fig. 2 is a block diagram illustrating calculation of fine offset terms used in the scene based nonuniformity correction method of the present invention that is employed in the imaging sensor system of Fig. 1; and

Fig. 3 is a flow diagram illustrating the scene based nonuniformity correction method in accordance with the principles of the present invention.

DETAILED DESCRIPTION

[0014] In order to better understand the present method or algorithm, reference is made to Fig. 1, which shows a block diagram of a generic scanning infrared sensor system 10, or imaging system 10, incorporating a scene based nonuniformity correction method 40 in accordance with the principles of the present invention. The scanning infrared sensor system 10 is comprised of a detector 11 and its readout 12, and the readout is coupled to system electronics 13 that implements scene based nonuniformity correction method 40. The system electronics 13 implements correction logic that produces coarse and fine correction terms that are applied to the processed video signal. The correction logic includes two offset and gain pairs, comprising a coarse offset and gain pair, and a fine offset and gain pair. The coarse offset and gain pair is comprised of coarse offset level and coarse gain terms 16, 17 that may be calculated using a thermal reference source (internal or external) and pre-stored in a nonvolatile memory 28. The coarse offset level term 16 may also be calculated using 8 thermal reference source which is updated continuously.

[0015] The fine offset and gain pair is comprised of fine offset level and fine gain terms 18, 19. The fine gain term 19 may be set to unity, calculated using thermal reference sources, or calculated using a scene-based algorithm. First and second adders 21, 23 and first and second multipliers 22, 24 are employed to appropriately combine the coarse and fine level and gain terms 16, 17, 18, 19 to produce a corrected video output signal. The present method 40 or algorithm is used to estimate the fine level correction terms 18 and is performed in a nonuniformity estimator 20. The output of the nonuniformity estimator 20 has a loop attenuation factor (k) 25 applied thereto and is coupled to a first input of a third adder 26. A second input of the third adder 26 is provided by the fine level term 18. As such the fine level term 18 is updated with the output of the nonuniformity estimator 20 multiplied by the loop attenuation factor (k) 25.

[0016] The expressions and equations that are used in implementing the present algorithm or method 40 will now be described. The variables associated with the system 10 are as follows:

$x(m, n)$ = input,

$y(m, n)$ = output,

$L_C(m)$ = coarse offset level term 16,

$G_C(m)$ = coarse gain term 17,

$L_F(m, n)$ = fine offset level term 18,

$G_F(m)$ = fine gain term 19,

$\hat{L}(m, n)$ = error estimate, and

k = loop attenuation factor 25,

where

$m = (0, M-1)$; M =number of detectors, and
 $n = (0, N-1)$; N = samples/detector.

[0017] The system input and output are thus related by the equation:

$$y(m, n) = G_F(m) \{ (G_C(m) [x(m, n) + L_C(m)] + L_F(m, n)) \}.$$

[0018] The fine level terms are recursively updated after each frame. Thus,

$$L_F(m, n) = L_F(m, n) + k \hat{L}(m, n).$$

[0019] Fig. 2 is a block diagram illustrating calculation of fine offset level terms 18 used in the scene based nonuniformity correction method 40 of the present invention that is employed in the scanning infrared sensor system 10 of Fig. 1. The following terms are defined and are used in implementing the method 40 of the present invention.

$\bar{y}_l(m)$ = horizontal average of a vertical region
 F_{hp} = high pass filter operator,
 $hp_l(m)$ = high pass version \bar{y}_l ,
 T = threshold operator,
 $b_l(m)$ = threshold version of \bar{y}_l ,
 B = segment boundary operator,
 F_{lp} = low pass filter operator,
 $lp_l(m)$ = low pass version of \bar{y}_l , and
 $c_l(m)$ = vertical region correction term,

where

$l = \{0, L-1\}$; L = number of regions, and
 $r = \{0, R-1\}$; R = samples/region.

[0020] During an active field time, the scene based nonuniformity correction method 40 collects scene data and calculates the average within each region, for each line therein, illustrated in box 31. This operation is equivalent to implementing the expression:

$$\bar{y}_l(m) = \frac{1}{R} \sum_{i=1R}^{(l+1)R-1} y(m, i).$$

[0021] $\bar{Y}_l(m)$ is thus comprised of several column vectors, or region vectors, \bar{y}_l , one for each region. These vectors are then high pass filtered (F_{hp}), illustrated in box 32, and thresholded (T), illustrated in box 33, to detect edges. The edges are marked as boundaries. Thus,

$$hp_l(m) = (F_{hp} \bar{y}_l)$$

$$b_l(m) = (T hp_l).$$

[0022] For locally high-pass filtering these vectors are then in a first step low pass filtered, illustrated in box 34, using the boundary information. Pixels marked as boundaries are ignored. This is denoted by the low pass filter operator, F_{lp} and the boundary operator, B . That is,

$$lp_l(m) = (F_{lp} (B \bar{y}_l)).$$

[0023] In a second step, each region vector, $\bar{y}_l(m)$, is subtracted from its low pass filtered version in an adder 35, producing the correction term for each region, $c_l(m)$. That is

$$c_l(m) = lp_l(m) - \bar{y}_l(m).$$

[0024] Finally, the correction terms are either applied individually for each region, or averaged together, wherein the boundary pixels are ignored. If they are averaged together, illustrated in box 36 the error estimate is calculated using the equation:

$$\hat{L}(m, n) = \frac{1}{L} \sum_{i=0}^L c_i(m).$$

[0025] For the purposes of completeness, Fig. 3 is a flow diagram illustrating the scene based nonuniformity correction method 40 in accordance with the principles of the present invention. A video input signal is provided, indicated in step 41, such as from the infrared sensor 11 derived from an image. The video input signal is processed such that a vector representing offset correction terms is formed, and this vector is initially set to zero. Each element in this vector represents a correction term for a particular detector of the scanning infrared sensor 11. The vector is applied to each pixel of the image by the processor 13 as the pixels are read from the focal plane array 12.

[0026] To measure the offset error, the image is separated into vertically oriented regions, each comprising a plurality of channels. The average of each channel within a region is computed, indicated in step 42, and a set of region vectors is formed, such that there is one region vector for each region. Each region vector is then globally high pass filtered, and edges larger than a predefined threshold are detected, indicated in step 43, and marked, indicated in step 44. Then, each region vector is further separated into sub-regions, indicated in step 45. The isolated sub-regions are high-pass filtered without regard to adjacent sub-regions, indicated in step 46, followed by a low-pass filtering step 47. In a first embodiment of the method 40, the correction terms for each vertical region vector are averaged together, resulting in a single correction vector, indicated in step 48.

[0027] The correction terms calculated for each vertical region may also be applied individually to each the detectors. In this second embodiment, the offset level error in each region for each channel is calculated, indicated in step 49, and wherein the offset level error at boundary edges is undefined because boundary pixels are ignored. The correction terms corresponding to a region are applied as the detector 11 scans the scene and views a portion corresponding to that particular region. The correction terms are smoothed at region boundaries to eliminate noise due to boundary transitions. This second method 40 is less sensitive to gain errors in the detector.

30 Claims

1. A scene based nonuniformity correction method (40) for use with a scanning infrared sensor comprising an array (11) of detectors, said method (40) comprising the steps of:
 - providing (41) a video input ($x(m, n)$) derived from an image;
 - processing the video input signal such that a vector representing offset correction terms is formed, wherein each element in the vector represents a correction term for a particular detector (m) of the scanning infrared sensor (11), and wherein the vector is initially set to zero, said processing further comprising the following steps:
 - separating the image into vertically oriented regions, each region (l) comprising a plurality of detector channels;
 - computing (42) an average ($\bar{y}_l(m)$) of each detector channel within a region (l) and forming from the thus obtained averages a set of region vectors (\bar{y}_l), such that there is one region vector for each region;
 - globally high-pass filtering (F_{hp} ; 32) each region vector whereby edges larger than a predefined threshold are detected (43), and marked (44);
 - separating (45) each region vector into sub-region vectors demarcated by the edges;
 - locally high-pass filtering (46) each sub-region vector;
 - computing (48, 49) the offset correction terms for each region vector from said high-pass filtered sub-region vectors; and
 - applying the offset correction terms to the video signal.
 - The method of Claim 1 wherein the step of computing (48, 49) the correction terms comprises the step of averaging (48) the correction terms for each region vector together to produce a single correction vector.
 - The method of Claim 1 wherein the step of computing (48, 49) the correction terms comprises the step of calculating (49) the offset correction term for each detector channel in each region, wherein the offset correction terms at the edges are ignored.

4. The method of Claim 1, 2 or 3 wherein the step of locally high-pass filtering (46) comprises the step of anti-median filtering a sub-region vector.
5. The method of Claim 1, 2 or 3 wherein the step of locally high-pass filtering (46) comprises the step of low-pass filtering a sub-region vector and subtracting the resultant vector from its corresponding original region vector (\bar{y}_l).
6. The method of Claim 1, 2 or 3 wherein the step of locally high-pass filtering (46) comprises the step of median filtering a sub-region vector and subtracting the resultant vector from its corresponding original region vector (\bar{y}_l).

10 Patentansprüche

1. Ein Verfahren (40) zur szenenabhängigen Korrektur von Ungleichmäßigkeit zur Verwendung mit einem abtastenden Infrarotsensor, der eine Gruppe (11) von Detektoren aufweist, wobei das Verfahren (40) die Schritte aufweist:
 - 15 Bereitstellen (41) eines von einem Bild abgeleiteten Videoeingangssignals ($x(m, n)$);
 - Verarbeiten des Videoeingangssignals, derart, daß ein Vektor gebildet wird, der Offsetkorrekturterme repräsentiert, wobei jedes Element in dem Vektor einen Korrekturterm für einen bestimmten Detektor (m) des abtastenden Infrarotsensors (11) repräsentiert, und wobei der Vektor anfangs auf Null gesetzt wird, wobei das
 - 20 Verarbeiten des weiteren die folgenden Schritte aufweist:
 - Aufteilen des Bildes in vertikal orientierte Bereiche, wobei jeder Bereich (l) eine Vielzahl von Detektorkanälen aufweist;
 - 25 Berechnen (42) eines Mittelwertes ($\bar{y}_l(m)$) für jeden Detektorkanal innerhalb eines Bereichs (l) und Bilden eines Satzes von Bereichsvektoren (\bar{y}_l) aus den so erhaltenen Mittelwerten, derart, daß es für jeden Bereich einen Bereichsvektor gibt;
 - global Hochpassfiltern (F_{hp} ; 32) eines jeden Bereichsvektors, wodurch Kanten, die größer als eine vorbestimmte Schwelle sind, detektiert (43) und markiert (44) werden;
 - 30 Aufteilen (45) eines jeden Bereichsvektors in Unterbereichsvektoren, die durch die Kanten abgegrenzt werden;
 - 35 lokal Hochpassfiltern (46) eines jeden Unterbereichsvektors;
 - Berechnen (48, 49) der Offsetkorrekturterme für jeden Bereichsvektor aus den hochpassgefilterten Unterbereichsvektoren; und
 - 40 Beaufschlagen des Videosignals mit den Offsetkorrekturtermen.
 2. Das Verfahren nach Anspruch 1, worin der Schritt des Berechnens (48, 49) der Korrekturterme den Schritt des Mittelns (48) der Korrekturterme für jeden Bereichsvektor aufweist, um einen einzelnen Korrekturvektor zu erzeugen.
 - 45 3. Das Verfahren nach Anspruch 1, worin der Schritt des Berechnens (48, 49) der Korrekturterme den Schritt des Berechnens (49) des Offsetkorrekturterms für jeden Detektorkanal in jedem Bereich aufweist, wobei die Offsetkorrekturterme an den Kanten ignoriert werden.
 4. Das Verfahren nach Anspruch 1, 2 oder 3, worin der Schritt des lokal Hochpassfilterns (46) den Schritt des Anti-medianfilterns eines Unterbereichsvektors aufweist.
 - 50 5. Das Verfahren nach Anspruch 1, 2 oder 3, worin der Schritt des lokal Hochpassfilterns (46) den Schritt des Tiefpassfilterns eines Unterbereichsvektors und Subtrahierens des sich ergebenden Vektors von seinem zugehörigen Originalbereichsvektor (\bar{y}_l) aufweist.
 - 55 6. Das Verfahren nach Anspruch 1, 2 oder 3, worin der Schritt des lokal Hochpassfilterns (46) den Schritt des Medianfilterns eines Unterbereichsvektors und Subtrahierens des sich ergebenden Vektors von seinem zugehörigen Originalbereichsvektor (\bar{y}_l) aufweist.

Revendications

1. Procédé de correction de défaut d'uniformité basé sur une scène (40), pour l'utilisation avec un capteur infrarouge à balayage comprenant un réseau (11) de détecteurs, ce procédé (40) comprenant les étapes suivantes :
 - on fournit (41) un signal d'entrée vidéo ($X(m, n)$) obtenu à partir d'une image ;
 - on traite le signal d'entrée vidéo de façon à former un vecteur représentant des termes de correction de décalage, chaque élément dans le vecteur représentant un terme de correction pour un détecteur (m) particulier du capteur infrarouge à balayage (11), et le vecteur étant fixé initialement à zéro ; ce traitement comprenant en outre les étapes suivantes :
 - on sépare l'image en régions orientées verticalement, chaque région (l) comprenant une pluralité de canaux de détecteur ;
 - on calcule (42) une moyenne ($\bar{y}_l(m)$) de chaque canal de détecteur à l'intérieur d'une région (l) et on forme à partir des moyennes ainsi obtenues un ensemble de vecteurs de région (\bar{y}_l), de façon qu'il y ait un vecteur de région pour chaque région ;
 - on effectue un filtrage passe-haut global (F_{hp} , 32) de chaque vecteur de région, grâce à quoi des bords supérieurs à un seuil prédéfini sont détectés (43), et marqués (44) ;
 - on sépare (45) chaque vecteur de région en vecteurs de sous-région délimités par les bords ;
 - on effectue un filtrage passe-haut local (46) de chaque vecteur de sous-région ;
 - on calcule (48, 49) les termes de correction de décalage pour chaque vecteur de région à partir des vecteurs de sous-région filtrés en mode passe-haut ; et
 - on applique les termes de correction de décalage au signal vidéo.
2. Procédé selon la revendication 1, dans lequel l'étape de calcul (48, 49) des termes de correction comprend l'étape consistant à faire la moyenne (48) de l'ensemble des termes de correction pour chaque vecteur de région, pour produire un seul vecteur de correction.
3. Procédé selon la revendication 1, dans lequel l'étape de calcul (48, 49) des termes de correction comprend l'étape consistant à calculer (49) le terme de correction de décalage pour chaque canal de détecteur dans chaque région, en négligeant les termes de correction de décalage aux bords.
4. Procédé selon la revendication 1, 2 ou 3, dans lequel l'étape de filtrage passe-haut local (46) comprend l'étape de filtrage d'anti-médiane d'un vecteur de sous-région.
5. Procédé selon la revendication 1, 2 ou 3, dans lequel l'étape de filtrage passe-haut local (46) comprend l'étape consistant à appliquer un filtrage passe-bas à un vecteur de sous-région, et à soustraire le vecteur résultant de son vecteur de région d'origine correspondant (\bar{y}_l).
6. Procédé selon la revendication 1, 2 ou 3, dans lequel l'étape de filtrage passe-haut local (46) comprend l'étape consistant à effectuer un filtrage de médiane d'un vecteur de sous-région et à soustraire le vecteur résultant de son vecteur de région d'origine correspondant (\bar{y}_l).

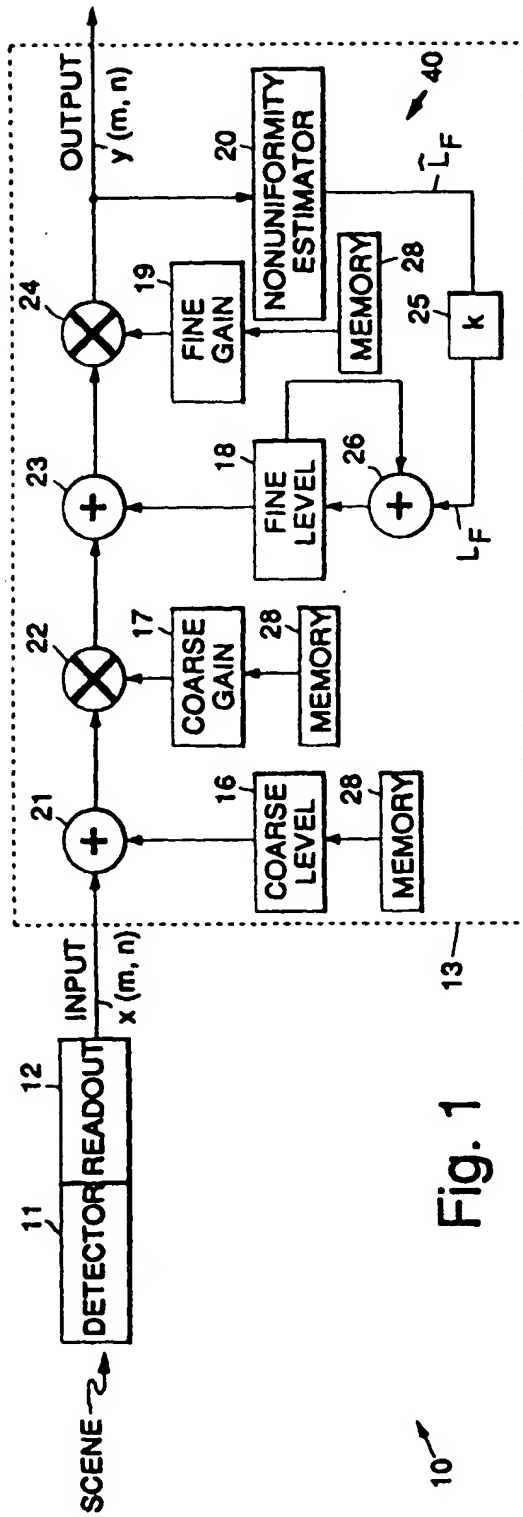


Fig. 1

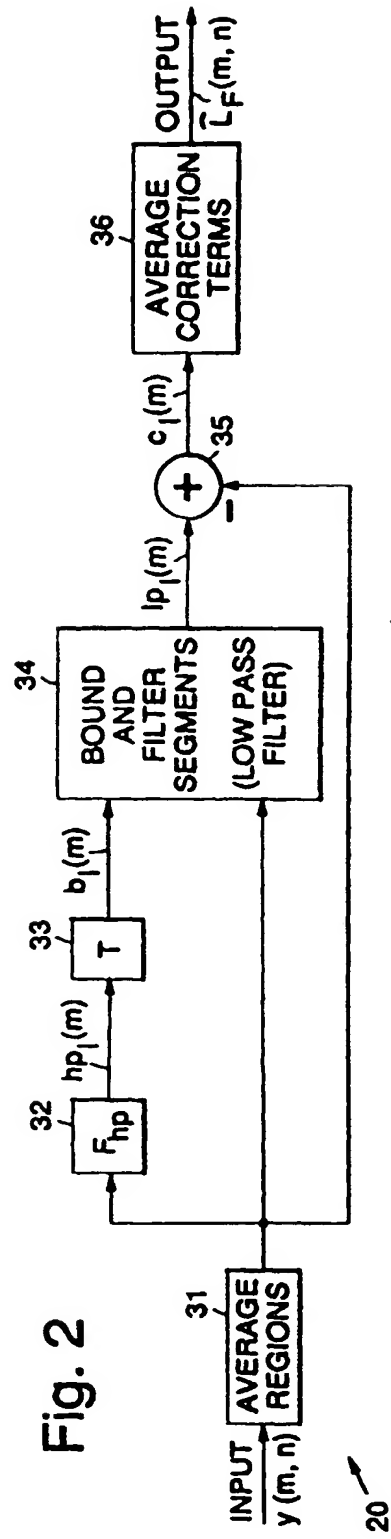


Fig. 2

Fig. 3

